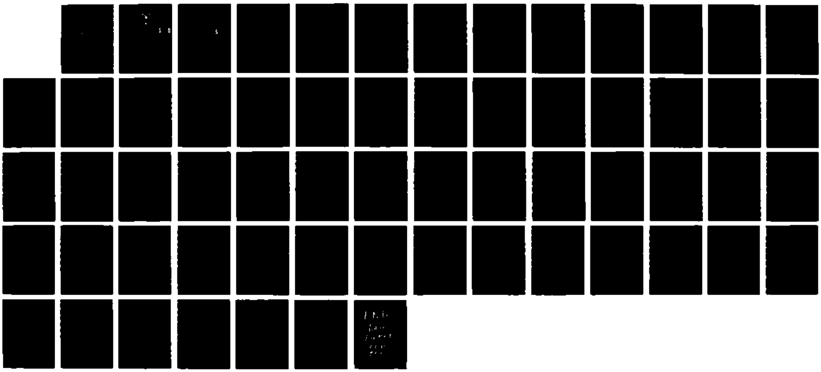
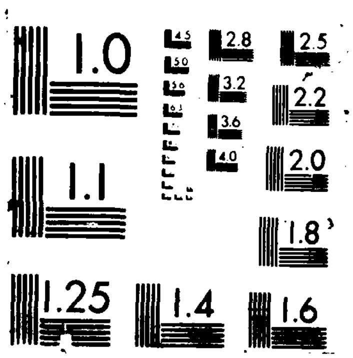
AD-A187 628 THE EFFECTS OF DATA STRUCTURE ON TOTAL TIME ON TEST PLOTS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. T J EDWARDS SEP 87 1/1

UNCLASSIFIED AFIT/GLM/LSMB/87S-21 F/G 12/4 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

THE EFFECTS OF DATA STRUCTURE ON

TOTAL TIME ON TEST PLOTS

THESIS

Thomas J. Edwards
Captain, USAF

AFIT/GLM/LSMB/87S-21

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GLM/LSMB/87S-21

THE EFFECTS OF DATA STRUCTURE ON

TOTAL TIME ON TEST PLOTS

THESIS

Thomas J. Edwards
Captain, USAF

AFIT/GLM/LSMB/87S-21

Approved for public release; distribution unlimited

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GLM/LSMB/87S-21

THE EFFECTS OF DATA STRUCTURE ON TOTAL TIME ON TEST PLOTS

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

Thomas J. Edwards

Captain, USAF

September 1987

Acknowledgements

The research was made possible with the help of a number of individuals. Special thanks goes to Major Phillip E. Miller for his assistance, direction, and enthusiasm that made this thesis possible. Additionally, I would like to thank Major Jonathan Kutzke for the help and insight that he provided. Finally, a special thanks goes to my wife, Edie. Her administrative help and patience was the driving force behind the completion of this project.

Table of Contents

List of Figures

Abstract

This research describes the effects data structure has on the Total Time on Test Transform technique and the resulting interpretation of the plot. Specifically, actual failure data on three card types (SUQ, BQQ, and BTJ) located in the Minuteman III Missile Guidance System was analyzed after manipulation. The manipulation consisted of the following three steps: 1) assign all zero time to failure values to the lowest failure time other than zero; 2) delete the zero time to failure values; and 3) delete all unusually high values from the sample data. After each step, the data was calculated and analyzed using Zenith 100 computer programs which performed the total time on test calculations and graphed those calculations into a total time on test data plot.

The results of this analysis indicated that data structure does influence total time on test plots. The deletion of the zero time to failure values causes a movement upward of the data plot which could 1) decrease the indication of decreasing failure rate (DFR), 2) increase or decrease the number of crossings on the 45 degree line, and 3) increase the indication of increasing failure rate (IFR).

THE EFFECTS OF DATA STRUCTURE ON
TOTAL TIME ON TEST PLOTS

I. Introduction

Chapter Overview

The purpose of this Chapter is to provide a general background on reliability and the Total Time on Test Transform (TTTT) technique as applied to certain management decisions. Additionally, Chapter I contains the specific problem and investigative questions addressed by this study as well as the scope of the study, limitations, and definitions of terms frequently used.

Background

Reliability in military systems has been a major concern throughout history. Many systems suffer from long periods of dormancy (storage or inactive use). A system taken out of storage is expected to accomplish its mission without a performance degrading malfunction. As systems have become more complex, sophisticated, and expensive, and their expected response time has become shorter, the need for reliability has increased. Missile systems spend a majority of their lifecycle in a non-operating environment. On newer missile systems, complexity is increasing, longer service lifes are required, and periodic maintenance and checkouts are being reduced or eliminated (18:7). In a typical missile system, even with periodic checkout, non-operating time could be as much as two million times longer than operating time. The operating failure rate is substantially greater than the non-operating failure rate. The significant

difference in these two states makes operating time a major factor to consider when attempting to estimate or project a missile system's reliability (18:18). The missile's guidance system operates under various levels of operational stress throughout its lifecycle and is considered a limiting factor in the reliability performance of the missile system (18:16).

The guidance system of the Minuteman Intercontinental Ballistic Missile System (ICBM) is the focal point for the system's reliability. It has displayed a dramatic increase in mean time between failures (MTBF) of a prior guidance system lifetime. When first deployed as a Minuteman I in the early 1960's, the MTBF of the guidance system was approximately 600 hours. This meant that the guidance system was removed fifteen times a year per missile. Each time the system was removed it took seven days to reinstall, calibrate, and warm up the guidance system to put it back on line. The average down time rate was 105 days a year. In 1963, $150 million was allocated to improve the reliability of the Minuteman system. The result of that investment was an increase of the MTBF rate to 9000 hours, saving $1.5 billion. Presently, the Minuteman III has more than 10000 hours mean time between failure (15:125).

An important concept in statistical reliability theory is the analysis of life data. If we place in operation a large number of new components of one type, the population will initially show a high failure rate if it contains a proportion of substandard, weak items. As these weak components fail, the failure rate decreases rapidly during the "infant mortality" or "burn in" period, and stabilizes to an approximately constant value. When the weak components have died out, the component population reaches its lowest failure rate level which is approximately constant. This approximately constant period of life is called the "useful life" period

of the component. It is in this period that the components can be utilized to the greatest advantage, and it is in this period that the exponential distribution is a good approximation. When the component's wearout begins to make itself noticeable, the failure rate displays a rapid increase. Knowing which period the failure rate occurred in provides management with information necessary to take the appropriate corrective action to increase the reliability of a system (6:33).

The total time on test concept is central in the analysis of life data for analyzing different aspects of the age replacement problem. The scaled TTT-Transform and TTT-Plot were first introduced by Barlow and Campo in 1975. These concepts have proven useful in the statistical analysis of failure data. In most applied situations, the life distribution is not known, but some observational data (failure history) may be available. The total time on test plots permit the analysis of incomplete data and provide a theoretical basis for such an analysis. The plots are on graphs that provide the same scale so that different types of distributions can be compared. The plots are scale invariant which eliminates the need for probability paper. Additionally, the plots provide direct information about the failure rate of an item (2:451-452).

Earlier research has used total time on test procedures to: 1) describe the failure distributions of selected Minuteman III electronic cards, 2) determine if the corresponding hazard function demonstrated infant mortality, useful life, or wearout, and 3) suggest management strategies to deal with wearout or infant mortality. In one study, five individual cards were selected and the first three lifetimes of each card were examined. The failure distributions were identified, but no management action was indicated due to the large mean lifetimes of the cards (16:4,59).

From man's earliest attempts to employ information from collected data as an aid in understanding populations, there has been a concern for "unrepresentative," "rogue," or "outlying" observations in sets of data. These are often seen as contaminating the data; reducing or distorting the information it provides about its source or generating mechanism. Observations that appear to be inconsistent with the remainder of that set of data may frustrate attempts to draw inferences about that population. The presence of possible 'outliers' and their effect are critical when evaluating the predictive capabilities of statistical procedures such as total time on test plots (5:11).

General Issue

The prediction of reliability is the process of forecasting future failures of an item from available failure rate information. Predictions use data from the failure history of items that are in operational use, not the reliability at the current state of development. To be most beneficial, the reliability predictions should be accomplished in a timely, useful manner at the conceptual and early design stages of the program and continue throughout the operational life of an item. Pure numerical values in themselves provide little benefit. The meaning of these numerical values, their relationships among the reliabilities of the various system elements, and the recommendations for system improvement in light of the predictions results are the real contributions of the predictions (1:149-150).

Specific Problem

The purpose of this research is to analyze the effect data structure has on the total time on test transform method and its corresponding

graphical representation in order to answer the following investigative questions:

1. Does the elimination of possible catastrophic failures affect the results obtained when using the total time on test transform method?

2. Determine the effects truncation has on the total time on test transform method.

3. Determine the robustness of total time on test plots (11:1).

Scope of the Study

This study does not evaluate the methods currently used to determine the reliability of the Minuteman III missile system. Neither does it analyze the methodology used in prior research, nor compare the reliability of the Minuteman system to other missile systems.

This study is intended to identify the relationships associated with the total time on test procedure and the specific results data structure has on the results obtained when using that procedure.

Limitations

There are several limitations inherent in this research that must be considered when evaluating the conclusions. First, the data used applies only to the Minuteman III missile system. No other missile system will be evaluated. Second, the data that will be used is current to January, 1986. No failure history beyond January, 1986 will be analyzed. Finally, no allowances for modifications and environmental factors will be made when this data is analyzed. Only the raw failure history data is being used. Additionally, the data that is being used was analyzed in a previous research effort (Sisk, 1986). This data and the results obtained from this data will be used for comparison purposes only.

Definitions

Catastrophic Failure - a failure that occurs that is not caused by component deterioration, but only by chance failure.

Dormancy - is defined (for the purpose of this report) as those states where a system or subsystem is not operating or is maintained in operationally ready storage including all maintenance and functional checks necessary to maintain the desired status. Guidance systems may be operating during various phases of the missile lifecycle prior to actual firing (18:18).

Lifecycle - the period of time from conceptual design through disposal of the system.

Lifetime - the time from when an item is put into operation until the time it fails (13:2).

Non-Operating - when a component is not experiencing electrical or mechanical stress. However, the component may be experiencing stress caused by the environment, transportation, and handling (18:16).

Operating - the state of a subsystem, assembly, or component when it is activated by electrical or mechanical means at any level of stress. An electronic subsystem such as a guidance unit may be operating at various levels of stress when it is tested in a check-out procedure (18:16).

Service Life - Air Force Regulation 136-1 defines service life as the length of time an item can remain installed in operating configuration or in actual use. For the purpose of this report, service life will be interchangeable with lifetime since the report deals with specific components of a major weapon system.

Truncate - to eliminate the high or low end of the data at a preassigned time point.

II. Literature Review

This portion of the research effort is devoted to examining the literature pertaining to failure characteristics and the impact those characteristics have on management policy. Particular attention is paid to decreasing failure rate (DFR), constant failure rate (CFR), and increasing failure rate (IFR). Additionally, the literature review examines the total time on test transform technique and how this technique evaluates failure data to provide management with the failure characteristics necessary to determine if a component is failing in useful life, infant mortality, or wearout. Knowing the failure characteristic displayed by an item is important to management because it provides information for making decisions such as the amount of burn-in time required and the time frame to perform parts replacement.

Reliability Assessment

When an item fails to operate under conditions encountered, the item is said to be unreliable (9:900). Unreliable equipment increases life-cycle costs due to repair activities and also affects mission accomplishment. In the past two decades there has been a change from deterministic to probabilistic methods of reliability assessment. This is due mainly because of the high risk environment that plant operators, designers, etc. operate under, requiring them to know whether their systems are reliable enough. The use of the word "enough" implies a quantification of reliability as a measurable entity. A general definition of reliability that has resulted is:

> Reliability is defined as that characteristic of an item expressed by the probability that it will perform its required function in

> the desired manner under all the relevant conditions and on the occasions or during the time intervals when it is required so to perform (9:900).

In high risk industries and when reliability is a consideration of readiness in national defense, it has become necessary to develop methods of prediction to obtain reliability assessments (9:902). In order to assess the reliability of a system, it is required to obtain the relevant variational or reliability data in the form of a distribution function, $F_H(x)$ (9:906). History has shown that when reliability is at a premium, reliability assessments can play an important role in the early design and subsequent operation of technological systems (9:906).

Failure Distribution

Failure distributions are an attempt to describe mathematically the length of life of an item to aid in reliability assessment. There are numerous ways an item (material, component, electrical device, etc.) can fail. Some examples of how electronic devices can fail are: an out of tolerance condition, environmental stress, improper design, and improper use. To base the failure distribution on these physical considerations is extremely difficult. For this reason, the failure rate function may be used in describing mathematically the length of life of an item (4:10).

When using actual observations of times to failure, it is difficult to distinguish among nonsymmetrical probability functions such as gamma, Weibull, and log normal. The significance of the distribution functions is only in the tails of the distribution which causes the sample size to be very important. In order to discriminate among probability functions, it is necessary to use a concept based on the failure rate function. In

reliability theory, this failure rate function has been termed the "hazard rate" (4:9-10).

Hazard Rate

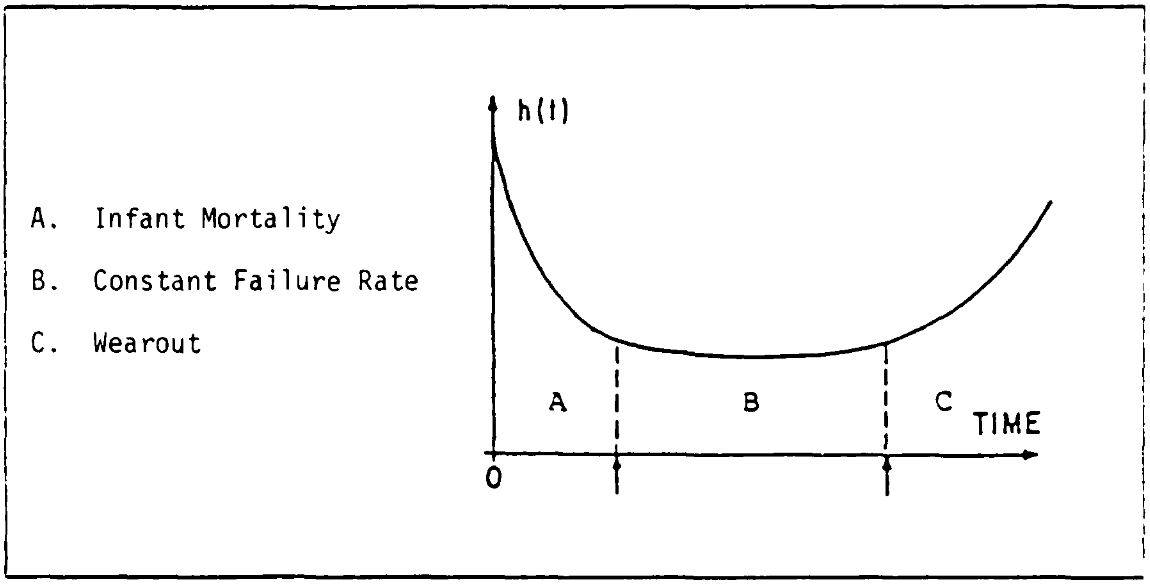
The hazard rate is a specialized notation that is useful in modeling failure time data. Many times the information is available on how the failure rate changes with the amount of time on test (12:9). The hazard rate is the instantaneous failure rate of a given item at a certain point in time or age of that item. The hazard rate is a measure of proneness to failure as a function of age. The hazard rate is also called hazard function, mortality rate, and the force of mortality (14:25).

A decreasing hazard rate during the early life of an item is termed infant mortality (also DFR). This often indicates the item is poorly designed or that defects occurred in the manufacturing of the item. An increasing hazard rate (also IFR) is an indication of a product wearing out or deteriorating with age to the point of failure. When an item shows a constant hazard rate, it is said to be in useful life (14:26).

Probability plotting methods are widely used in applied statistics. The plots provide (1) a descriptive capacity which clarifies the structure of data, (2) sufficient accuracy for most applications, and (3) a means for analyzing contaminated data or data that contains possible outliers. Additionally, hazard rate plots can provide a method for describing failure distributions, estimating parameters of a distribution, and the failure rate of components as a function of their age (2:451-452). A widely used hazard rate plot in reliability assessment is the bathtub curve.

Bathtub Curve

When the hazard rate is plotted against time, the resulting pattern often follows the pattern known as the "bathtub curve." Three noticeable periods that differ in the frequency of failure and in failure causation are noticeable - infant mortality, constant failure rate period, and wear-out period (Figure 1).



(14:27)

Figure 1. Bathtub Curve

The terms infant mortality, useful life, and wearout are based upon studies conducted by life insurance companies that indicated human populations experience a large number of deaths (failures) early in childhood (infancy) due to a multitude of factors. This death rate declines over time (age) to a constant rate (useful life). When the death rate begins to show an increase due to aging, the wearout period begins (14:25). Hazard rate plots exhibit similar characteristics when the failure data of electronic and mechanical components are used (11:203).

The infant mortality period, also known as decreasing failure rate (DFR), is distinguished by the high failure rate early in the use of an item. The high failure rate in early use is an indication to management of possible errors in design or manufacture, misuse, or misapplication. Very often management is able to correct this problem by overstressing (in electronics "burn in" or environmental stress screening) until the weak units fail. The items still fail, but the failure occurs before the item is put into operational use (11:203).

The constant-failure-rate period is characterized by the exponential distribution. The limitations that resulted in the high failure rate early in the item's life are no longer present. The failures that result during the constant-failure-rate period are usually caused by changes in the environment, accidents, or poor maintenance. It is generally accepted by management that the only way to reduce the failure rate during this period is by changing the basic design of the item, possibly by using redundancy, or using overspecified components (11:204).

The wearout period, or increasing failure rate (IFR) period, is an increase in the failure rate of an item due mainly to the deterioration of performance or old age. Management would be concerned with replacing or doing periodic maintenance on the items before an item reaches this period and results in a catastrophic failure (11:204). The accuracy of the prediction is critical to management's policy selection. An important factor is matching the procedure used in making that prediction to the type of data that is available.

Data Types

The type of data is critical to proper analysis. There are two major categories of data: complete and incomplete. Complete data is when the

value of each sample unit is observed to the time of failure. When the exact failure time of some units is unknown, and there is only partial information on their failure times, the data is said to be incomplete. When life data are analyzed, some units might not have failed yet, and their failure times are known only to be at some future time. This data is said to be censored on the right and is an example of incomplete data. Another example of incomplete data is when units are inspected for failure at one time period. When this procedure is used, it is only known that the unit failed in the interval between inspections. This is an example of interval or grouped data. Interval data can also contain right and left censored observations (14:7-9).

Total Time on Test Plot

The total time on test plot provides a method for analyzing complete and incomplete data. The test was developed to predict in which area of the bathtub curve the failures are occurring. Additionally, by using a plot of the total time on test transform method, it is possible to determine the underlying failure distributions. This is possible by using overlays of known distributions and in the case of an exponential distribution, the crossing check (7:175). In the case of an item being examined, a failure is obviously costly in terms of readiness and manhours required to repair an item. With the information provided by the total time on transform method, it is possible to determine that if used units are more prone to failure than newer ones, perhaps it would be to management's advantage to replace a used component after a certain period of time. This is often referred to as "new better than used" (8:467).

The total time on test plot was first developed by Barlow and Campo as a method to aid in the determination of the failure distribution of

an item when using observed data. The procedure graphically shows the transform of an empirical failure distribution (4:451-453).

The total time on test statistic is calculated as follows: Given a random sample

$$X_1, X_2, \ldots, X_n \tag{1}$$

from a life distribution F, then by ordering from lowest to highest

$$X_{(1)} < X_{(2)} < \ldots < X_{(n)} \tag{2}$$

the results are in the ordered observations. Then, the summations of the ordered observations

$$T(X_{(i)}) = \sum_{j=1}^{i} X_{(j)} + (n - i)\, X_{(i)} \tag{3}$$

is defined to be the total time on test until the ith failure.

In general, if the number of items on test at time u is denoted by n(u).

$$T(x) = \int_0^x n(u)\, du \tag{4}$$

is the total time on test till X.

The total time on test defined above is not scale dependent and is scaled by dividing by $T(X_{(n)})$.

$$H_n(i/n) = \frac{T(X_{(i)})}{T(X_{(n)})} \, . \tag{5}$$

$H_n(i/n)$ is defined as the total time on test until the ith failure and the plot of $(i/n, H_n(i/n))$ is known as the emperical scaled total time on test. $H_n(0) = 0$ is defined so that the plot lies in the unit square and is 0 at 0 and 1 at 1 (3:365-366).

The constant failure rate area of the total time on test plot, or exponential distribution, is depicted by a 45 degree line drawn from the origin and proceeding up to the right. If the underlying distribution is exponential it can be shown that $(H_n(\frac{1}{n}), \ldots, H_n(\frac{n-1}{n}))$ are jointly distributed like the order statistics from a sample of size n-1 from a uniform [0,1] distribution and the plot of $H_n(\frac{i}{n})$ will lie close to the diagonal line. Increasing failure rate (IFR) is identified by a concave shape; decreasing failure rate (DFR) is identified by a convex shape (3:367).

Figure 2 depicts the scaled total time on test plots of selected Weibull distributions. The total time on test plot of an exponential distribution (β=1) is the diagonal, the IFR distribution is the concave curve and the DFR distribution is the convex curve (3:368).

Barlow and Campo identify the application of TTT plots as applied towards three types of incomplete data. The three types discussed are grouped data, censored data, and truncated data. Grouped data as defined by Barlow and Campo is failure data recorded in terms of the number of failures within specific time intervals. Truncated data is observation terminated at a specified time and the number of failures are less than the total number of items observed. Finally, censored data is when the testing stops at some predetermined number of failures (2:461-463).

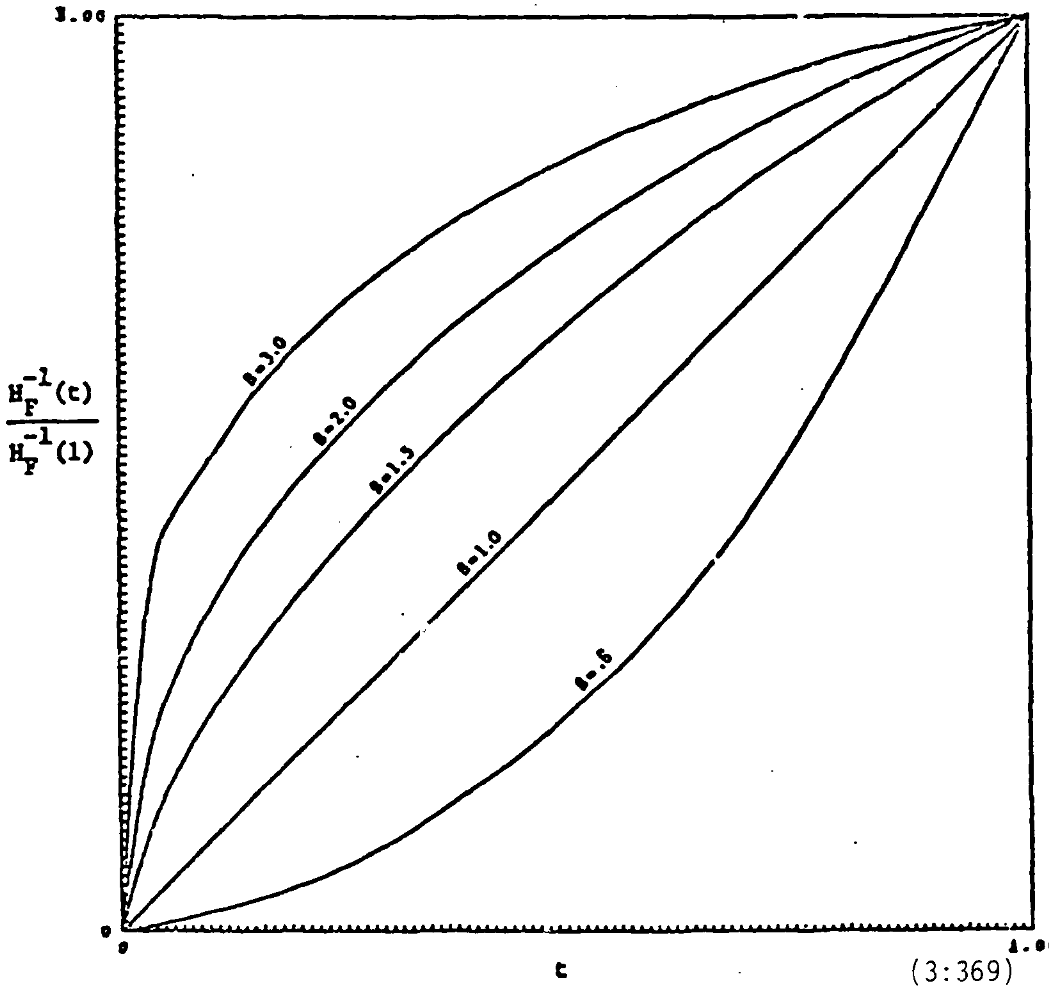


Figure 2. Total Time on Test Transform
of Selected Weibull Distributions

An additional description of the failure data provided by Barlow and Campo (1975) is the "crossing test." The crossing test provides a test of exponentiality that differs from the IFR/DFR alternative. Add the number of crossings (Ln) between the TTT plot and the 45 degree line, and reject the hypothesis of exponentiality when Ln is small (2:465). The crossing test is based on the following theorem:

> If F is exponential and N is the number of observed failures, then the probability (total time on test plot lies above the 45 degree line) = probability (total time on test lies below the 45 degree line) and that equals $\frac{1}{N}$ (2:465).

Summary

This literature review examined failure distributions and the hazard rate and their application in determining the IFR, DFR, or useful life when using probability plotting or total time on test methods. Additionally, an explanation of how the total time on test procedure is used to graphically represent the hazard rate is discussed.

The literature review also stresses the importance of data selection and the quantification of reliability assessment when providing management with methods of prediction. Chapter III provides the methodology used by this research effort to determine the effects data selection has on the predictive capabilities of the total time on test method.

III. Methodology

This Chapter describes the methods used to answer the investigative questions posed in Chapter I. Additionally, a description of the data used and an explanation of the data selection method is provided.

Introduction

This research is concerned with the effects data selection has on the total time on test transform method and its corresponding plot. To accomplish this analysis, data that was previously analyzed will be used, manipulated, and consequently plotted using the total time on test transfer method.

The total time on test program used is an adaptation of a Fortran program formulated by Lt. Col. Carlos Talbott, HQ USAF/LE-RD, in support of his doctoral dissertation research. To be compatible with the computer system used by this and previous research, the program was rewritten in GWBASIC and ZBASIC by Maj. John Kutzke, AFIT/LS, and modified by Capt. William Rimpo. An example of the GWBASIC program is provided in the Appendix. The program utilizes the formulas described in Chapter II of this thesis to perform the total time on test calculations.

Data Description

The data used in this research was provided by the Statistical Analysis Branch of the Material Management Engineering Division located at Ogden Air Logistics Center (OOALC/MMEAS) on a magnetic tape configured on a 116-column record length, 30 records per block, 3480 blocks format. The data was formatted at 5250 bytes per inch (BPI) and labeled in the Extended Binary Coded Decimal Interchange Code (EBCDIC) format. It was

determined that this format was not compatible with the magnetic tape reading equipment available for research support at AFIT (18:25). Therefore, it was necessary to reformat the data into a 116-column record length, 60 records per block, 6960 blocks, unlabeled, American Standard Code Information Interchange (ASCII) format to be compatible with the AFIT system.

The data provided 44 different types of electronic cards extracted from the Repair and Evaluation Data System (RED) master tape. There is no field repair of the Missile Guidance System (MGS); a failure constitutes a replacement action. When an MGS fails, it is normally returned to Newark AFS, Ohio for repair. The repair of the MGS is accomplished by replacement of one or more of the components, assemblies, subassemblies, etc. The Repair and Evaluation Data System is used to document these repair actions for the purpose of expeditiously gathering, sorting, processing, and distributing critical data on the performance analysis of initial subsystems during the maintenance and repair cycle. The data extracted from the RED tape is configured sequentially by card type (alphabetically) and by serial number within each card type. Air Force Logistics Command (AFLC) regulation 66-308, attachment 3, provides a complete description of the data format.

The data on the 44 card types pertained to two components within the Minuteman III Guidance System, the Missile Guidance Set Control and the Stabilized Platform. Five cards were previously selected for analysis (Sisk), four from the Guidance Set Control, and one from the Stabilized Platform. The cards were selected due to their having more than two lifetimes and the large populations of their failure data contained on the tape. This research effort will be concerned with three specific card types within the missile guidance set control subsystem, BQQ, BTJ, and SUQ.

Data Selection

The data being used in this research effort was previously separated into particular lifetimes by card types using a Fortran program developed by Sisk. Each lifetime that was segregated contained: 1) cards that failed a particular number of times, and 2) cards that were removed from service for reasons other than a failure. Sisk additionally broke down the segregated lifetimes into files containing failures only and files that contained removals for reasons other than failures and identified the failure file as uncensored data and the removal for other than failure file as censored data. He then analyzed the data by using each card type's individual lifetime as a separate group. For a complete description of the data selection, see Sisk, 1986.

Particular Method

The data that was analyzed by Sisk, in many cases, contained values that indicated zero time on test before failure and zero time on test without a failure. Additionally, the data contained some values that were considered by this researcher to be unusually high compared to the bulk of failure times. The methodology used by this research is directed at finding out what effect manipulation of these data points has on the resulting TTT plots. The following is the sequence of the data manipulation:

1. Identify the data points that contain a zero time on test value.

2. Incorporate the zero values to the numerical time on test value as the smallest data point that contains a non-zero value and retain the original sample size.

3. Reject the zero values from the data set under the assumption that they are catastrophic failures.

4. Reject unusually high values (if applicable) under the assumption that they are possible outliers.

After steps 2, 3, and 4, the remaining data will be subjected to the total time on test program described earlier using a Zenith 100 computer. The resulting calculations, using the total time on test graphical technique, were plotted using the GRAFTALK software that is available for the Zenith 100 computer.

Summary

This portion of the research effort explained the methodology used to determine if the elimination or incorporation of possible catastrophic failures or the elimination of possible outliers affects the results obtained in the total time on test method developed by Barlow and Campo. The following Chapter contains the analysis and results of this research effort.

IV. Results

This Chapter reports the results of the data analysis performed using the methodology described in Chapter III. The results will be reported by card type and lifetime order.

SUQ Card Type Results

The first electronic card type failure data to be manipulated was the circuit cards that contained the serial number prefix of SUQ. SUQ denoted the circuit cards that are located on the x, y, or z ECA accelerometer located in the Minuteman III Guidance System.

The first lifetime data evaluated by Sisk contained no zero time on test to failure values and no unusually high values to be manipulated or deleted by this research effort. The total time on test plot is shown in Figure 3; the sample size evaluated contained 157 observations.

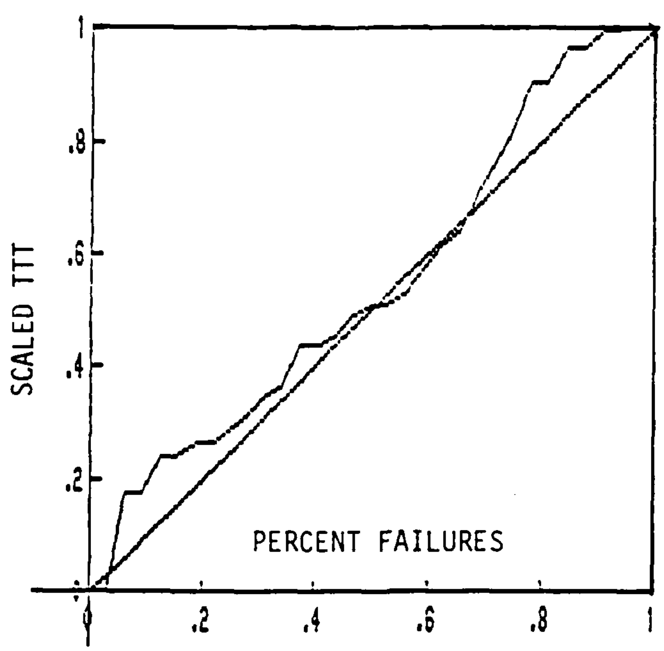


Figure 3. SUQ 1st Lifetime (Original Data)

The second lifetime of the SUQ card type contained a sample size of 63 observations, no unusually high values and one zero time to failure value with no failure indicated, i.e., a 0,0 value. The TTT plot is shown in Figure 4. This zero value was assigned to the lowest time on test value (non-zero) and resulted in the TTT plot depicted in Figure 5, showing no noticeable difference from the plot of the original data. The next step required the deletion of the zero value, decreasing the sample size to 62 observations. The resulting TTT plot, Figure 6, again displayed no noticeable change from the original data plot. Step four of the methodology was not accomplished because there were no unusually high values.

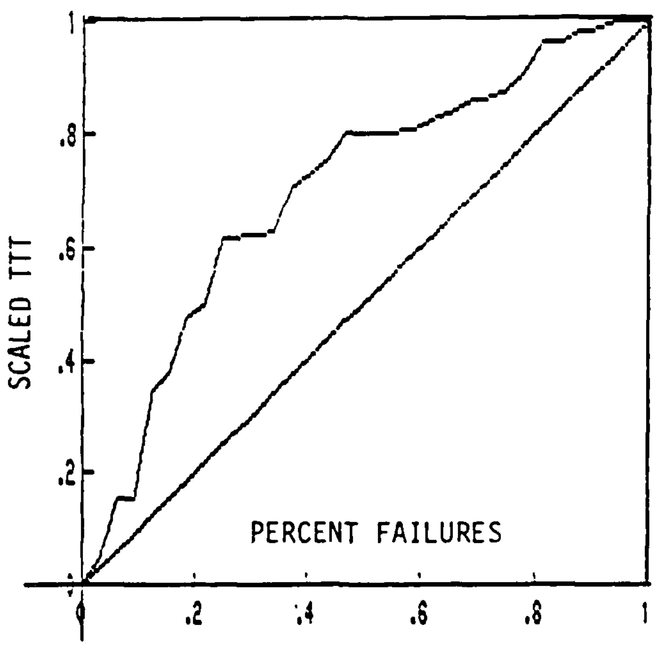


Figure 4. SUQ 2nd Lifetime (Original Data)

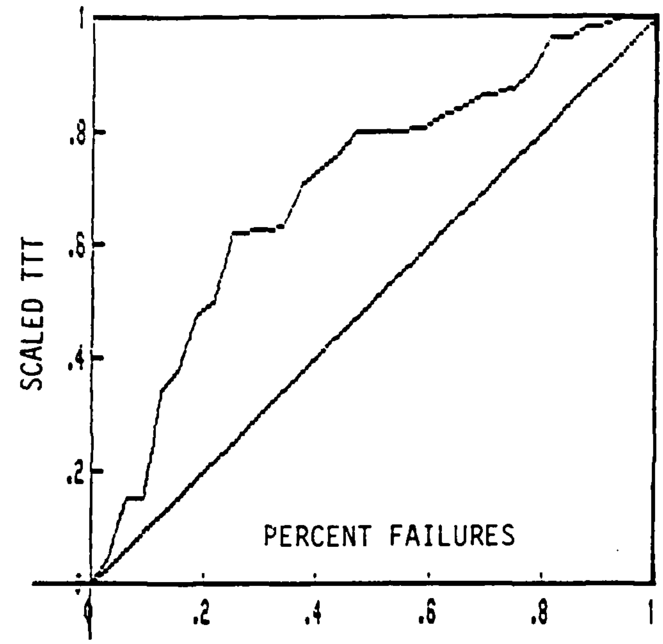


Figure 5. SUQ 2nd Lifetime
(Zero Values Assigned to 54)

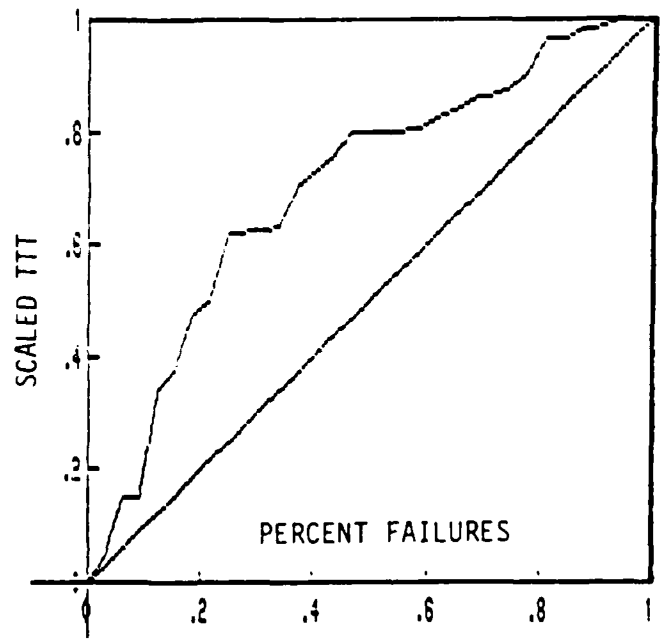


Figure 6. SUQ 2nd Lifetime
(Zero Values Deleted)

The third lifetime of the SUQ card type data being analyzed contained a sample size of 100 observations. The observations contained seven zero values of which two indicated an actual failure, i.e., 1,0. Additionally, the data contained one value that was unusually high that could be considered a possible outlier. The TTT plot of the original data is depicted in Figure 7. The zero values were assigned the value of 29 and resulted in the plot shown in Figure 8, with little change from the plot of the original data. The next step, involving deletion of the zero values and decreasing the sample size to 93, resulted in the TTT plot shown in Figure 9. The deletion of the zero values moved the TTT plot closer to the 45 degree line. The final step of deleting the high value, Figure 10, resulted in removing the area of the plot that was located above the 45 degree line.

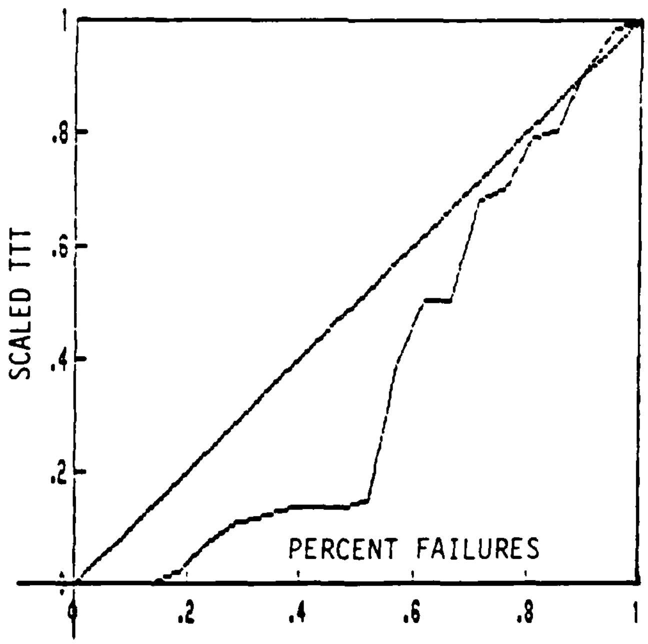


Figure 7. SUQ 3rd Lifetime (Original Data)

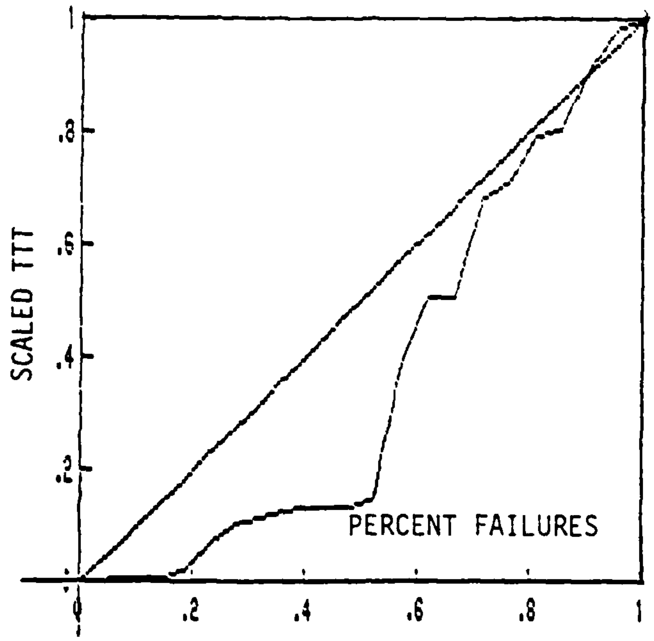


Figure 8. SUQ 3rd Lifetime
(Zero Values Assigned to 29)

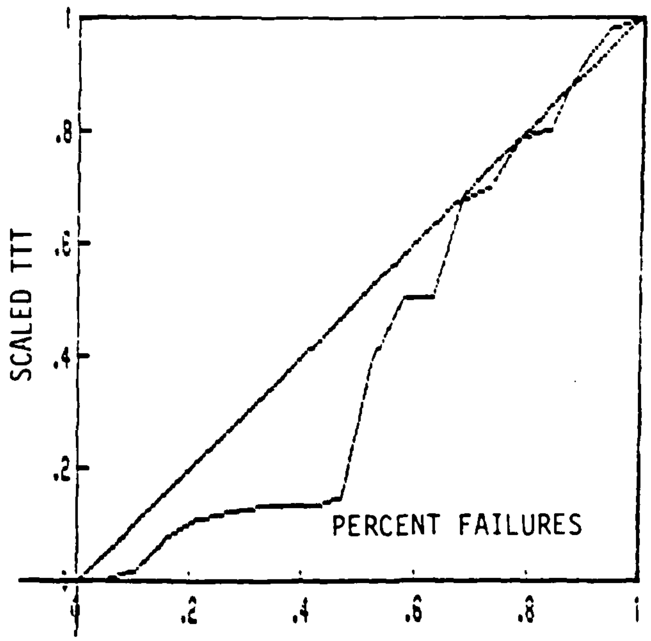


Figure 9. SUQ 3rd Lifetime
(Zero Values Deleted)

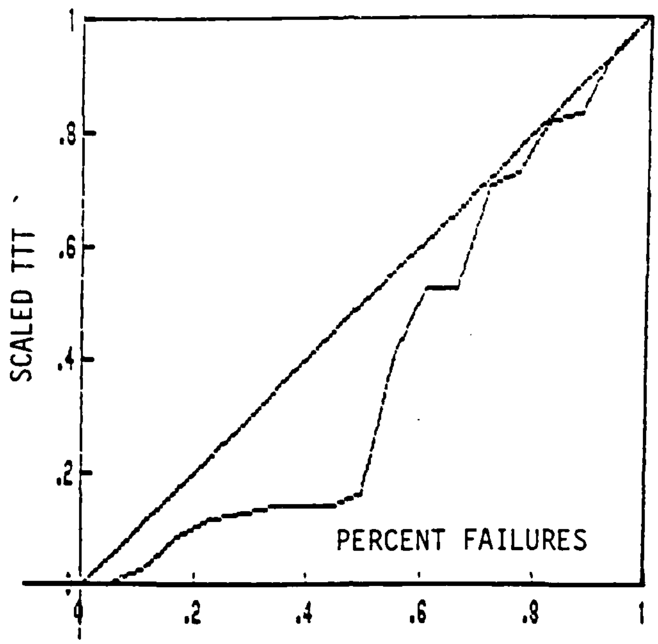


Figure 10. SUQ 3rd Lifetime
(High Value Deleted)

BQQ Card Type Results

The second card type failure data used by this research effort contained the serial number prefix BQQ. The BQQ serial number prefix indicates the circuit cards are located in the 400 cycles per second fan power supply in the Minuteman III Guidance System.

The first lifetime of the BQQ card type contained a sample size of 112 observations. Within that sample, there were no zero values and no unusually high values. The TTT plot is exhibited in Figure 11.

The second lifetime contained a sample size of 57, within which there were four zero values and one unusually high value. The zero values were composed of two failures and two non-failures with zero time on test. The resulting TTT plot of the original data of the second lifetime before manipulation is shown in Figure 12. The assigning of the zero values to the next highest non-zero value, 86, resulted in the TTT plot depicted in Figure 13, with no appreciable change from the plot of the original data.

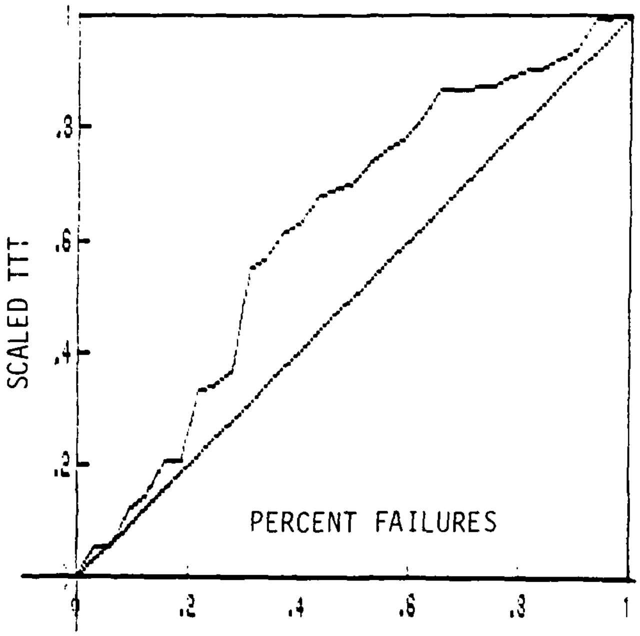


Figure 11. BQQ 1st Lifetime (Original Data)

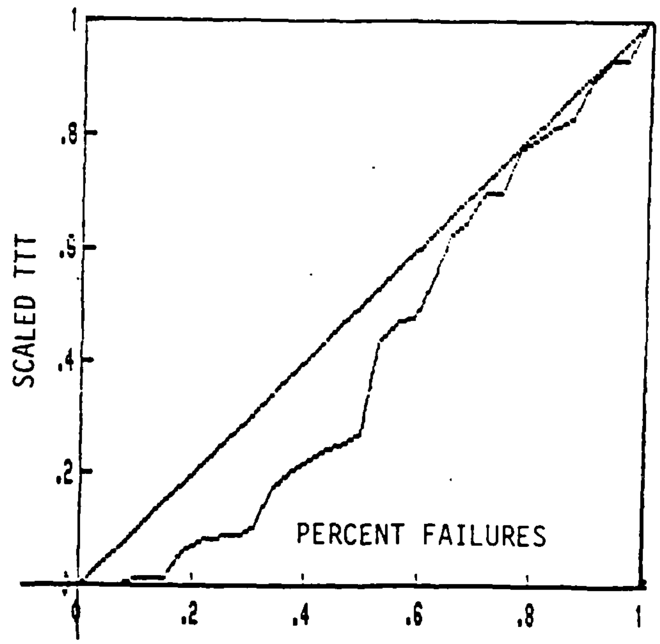


Figure 12. BQQ 2nd Lifetime (Original Data)

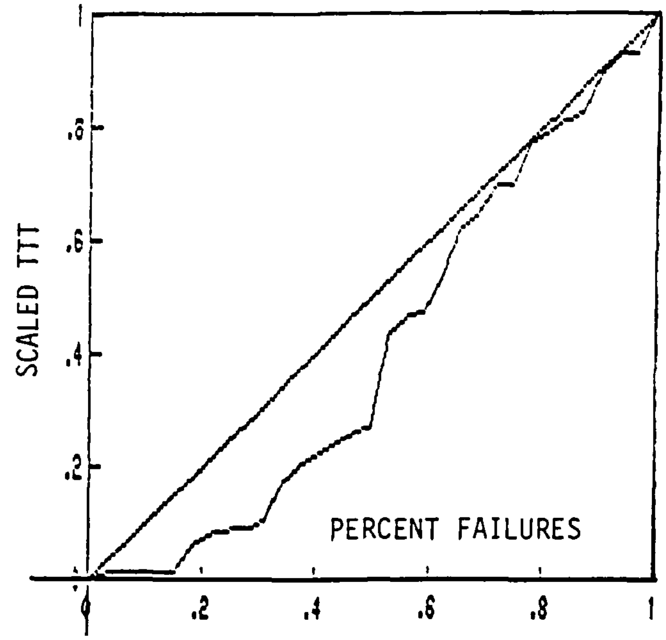


Figure 13. BQQ 2nd Lifetime
(Zero Values Assigned to 86)

The deletion of the zero values resulted in Figure 14, which shifted the TTT plot closer to the 45 degree line. Finally, when the unusually high value was deleted, resulting in a sample size of 52, part of the TTT plot crossed the 45 degree line into the IFR region as shown in Figure 15.

The third lifetime of the BQQ card type's data contained a sample size of 122 observations. The sample encompassed five zero values and one unusually high value. The five zero values contained four zero failures with zero time on test and one failure with zero time on test. The TTT plot of the original data is shown in Figure 16. The resulting TTT plot, Figure 17, after assigning the zero values to the next highest non-zero value (24), shows no noticeable change from the plot of the original data. Deletion of the zero values reduced the sample size to 117 and resulted in the plot shown in Figure 18. This plot shows a slight movement away from the 45 degree line into the IFR region of the graph. The last step of deleting the high value, Figure 19, shows no noticeable difference from Figure 18.

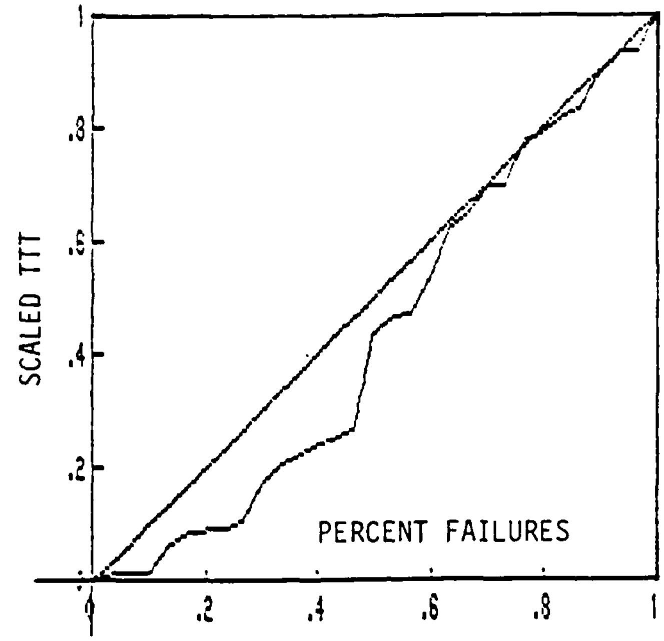


Figure 14. BQQ 2nd Lifetime
(Zero Values Deleted)

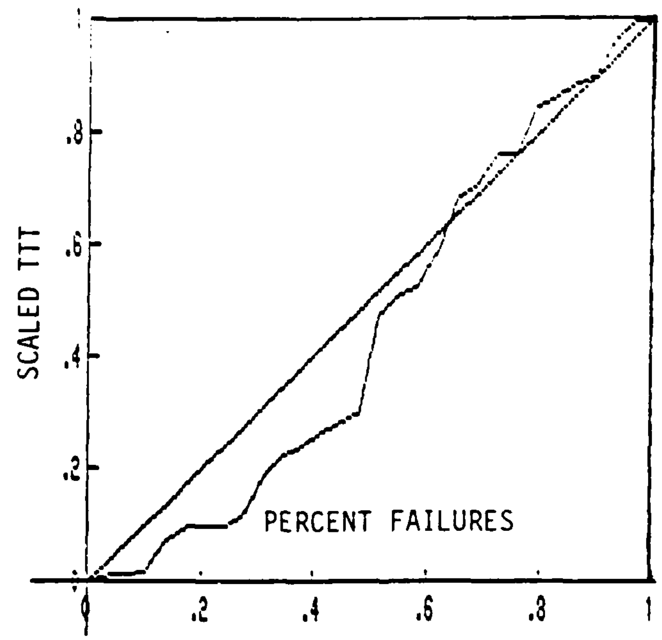


Figure 15. BQQ 2nd Lifetime
(High Value Deleted)

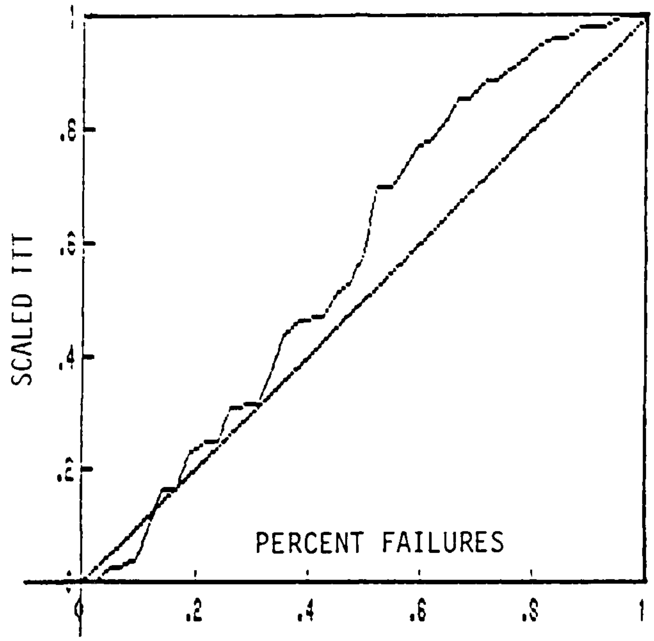


Figure 16. BQQ 3rd Lifetime (Original Data)

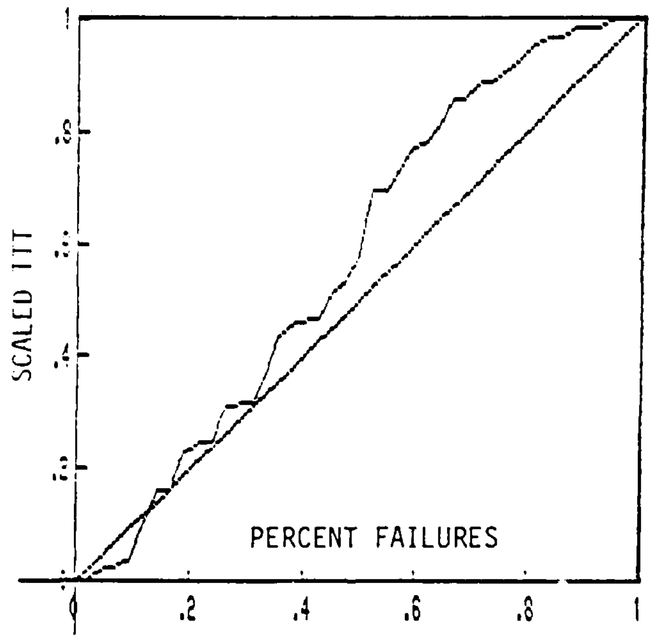


Figure 17. BQQ 3rd Lifetime
(Zero Values Assigned to 24)

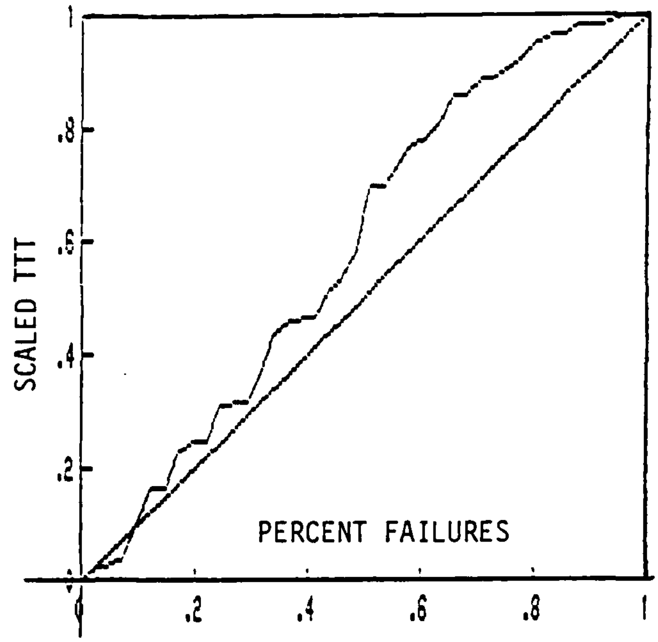


Figure 18. BQQ 3rd Lifetime
(Zero Values Deleted)

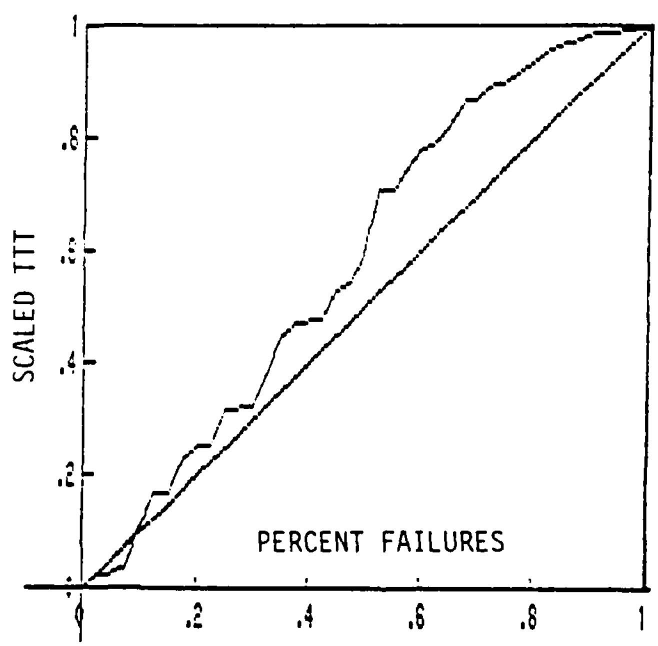


Figure 19. BQQ 3rd Lifetime
(High Value Deleted)

BTJ Card Type Results

The final card type's data observed contained the BTJ serial number prefix. The BTJ card type is located on the missile guidance set control located in the Minuteman III Guidance System.

The first lifetime contained a sample size of 114 observations. The sample contained five zero values and one unusually high value. The five zero values consisted of four indicated failures and one non-failure with zero time on test. The TTT plot of the original data is shown in Figure 20. No noticeable change in the plot occurred when the zero values were changed to the next higher non-zero value, 63, shown in Figure 21. When the zero values were deleted, lowering the sample size to 109, the plot displayed a noticeable shift towards the IFR region of the graph, Figure 22. No noticeable change occurred when the unusually high value was deleted from the data, shown in Figure 23.

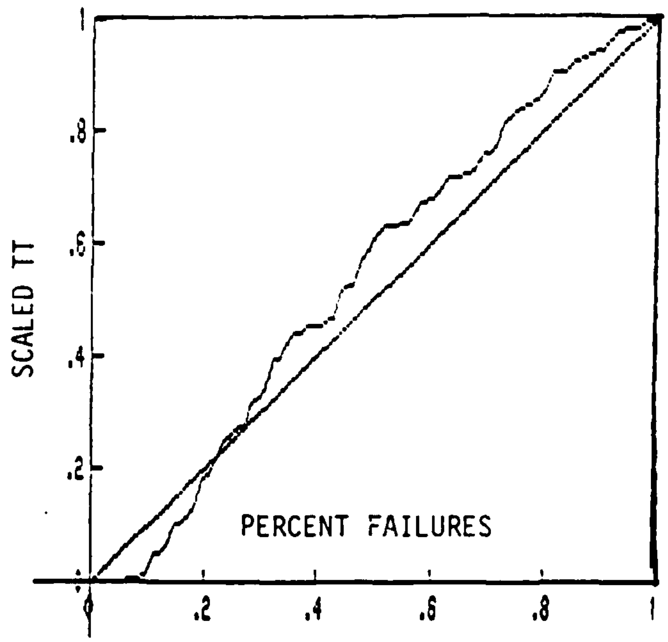


Figure 20. BTJ 1st Lifetime (Original Data)

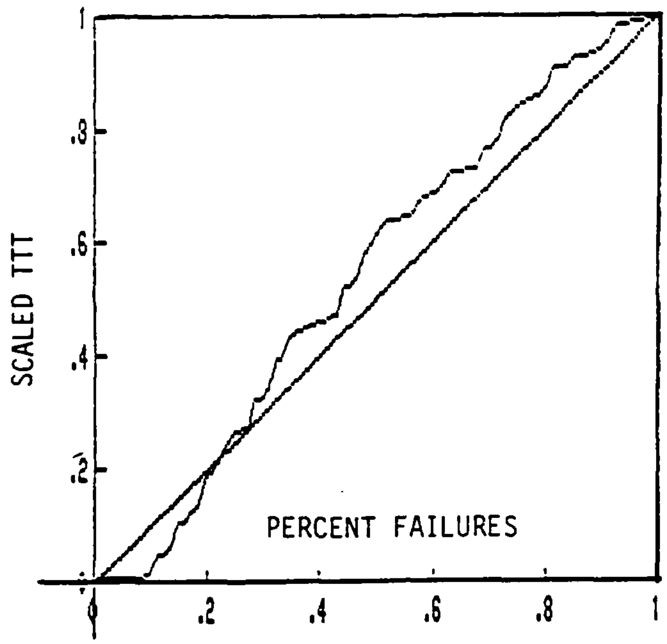


Figure 21. BTJ 1st Lifetime
(Zero Values Assigned to 63)

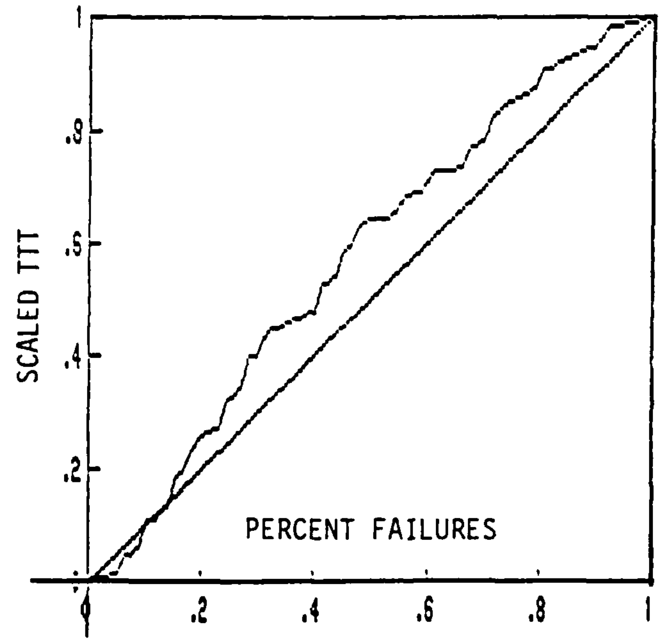


Figure 22. BTJ 1st Lifetime
(Zero Values Deleted)

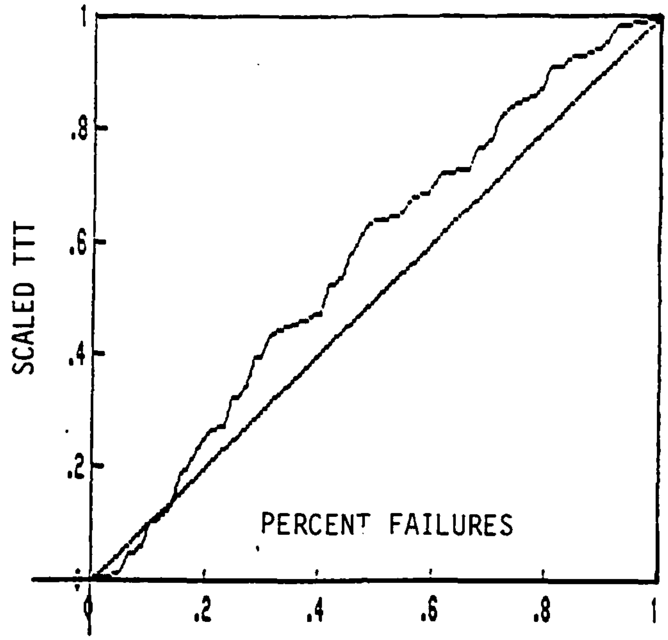


Figure 23. BTJ 1st Lifetime
(High Value Deleted)

The second lifetime consisted of a sample size of 175 observations. Within this sample there occurred 12 zero values and one unusually high value. The 12 zero values consisted of 11 non-failure indications and one failure indication with zero time on test. The TTT plot of the second lifetime of the BTJ card type's original data is depicted in Figure 24. The assignment of the zero values to the next highest non-zero value of 29 resulted in the TTT plot shown in Figure 25, displaying no noticeable change in the graph. When the zero values were deleted, the plot displayed a noticeable shift above the 45 degree line into the IFR region of the graph, Figure 26. No noticeable change occurred when the high value was deleted in Figure 27.

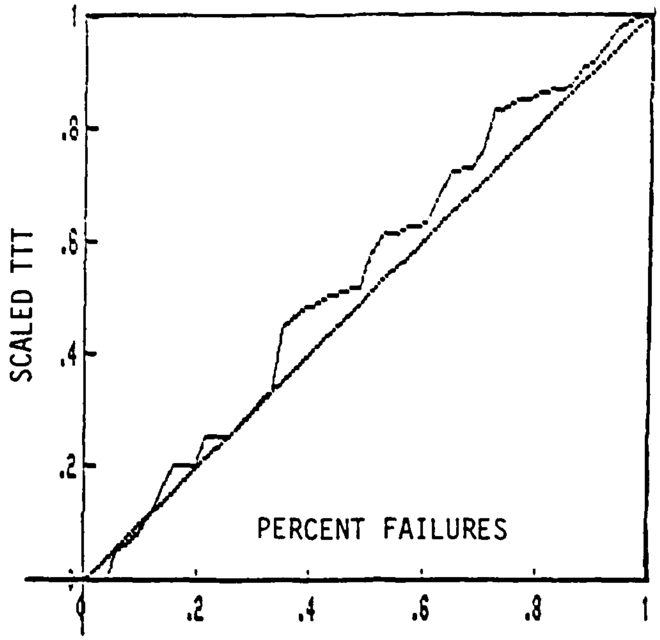


Figure 24. BTJ 2nd Lifetime (Original Data)

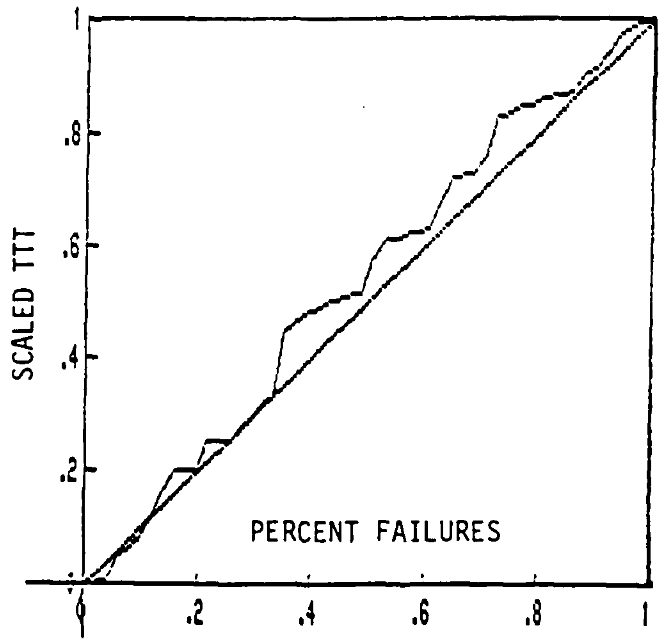


Figure 25. BTJ 2nd Lifetime
(Zero Values Assigned to 29)

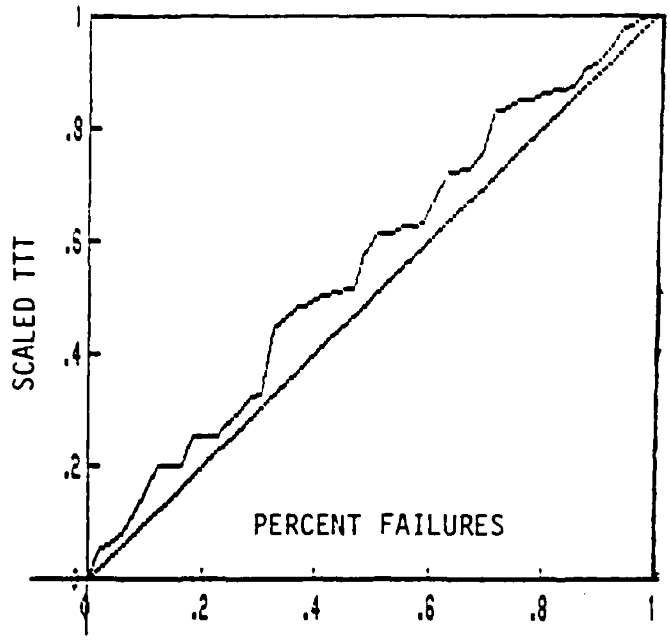


Figure 26. BTJ 2nd Lifetime
(Zero Values Deleted)

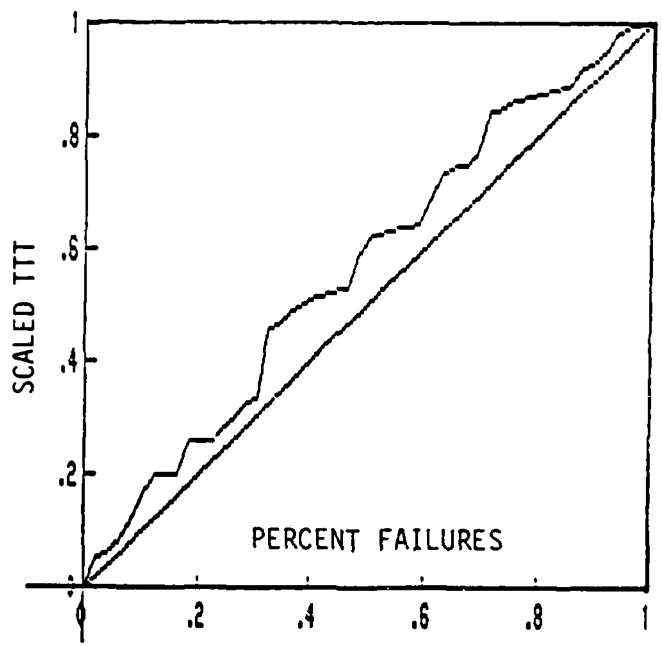


Figure 27. BTJ 2nd Lifetime
(High Value Deleted)

The third lifetime of the BTJ card type contained a sample size of 122 observations. The sample included 11 zero values and one unusually high value. The 11 zero values encompassed nine non-failures and two failures with no time on test. The TTT plot of all 122 observations is displayed in Figure 28. The resulting plot, after the zero values were assigned the lowest non-zero value of 33, is shown in Figure 29. The assignment of the zero values to the time on test of 33 hours snowed no noticeable change from the plot of the original data. Figure 30 indicates the movement of the plot towards the 45 degree line when the zero values were deleted and the sample size decreased to 111. The final plot, Figure 31, shows little change when the unusually high value is deleted.

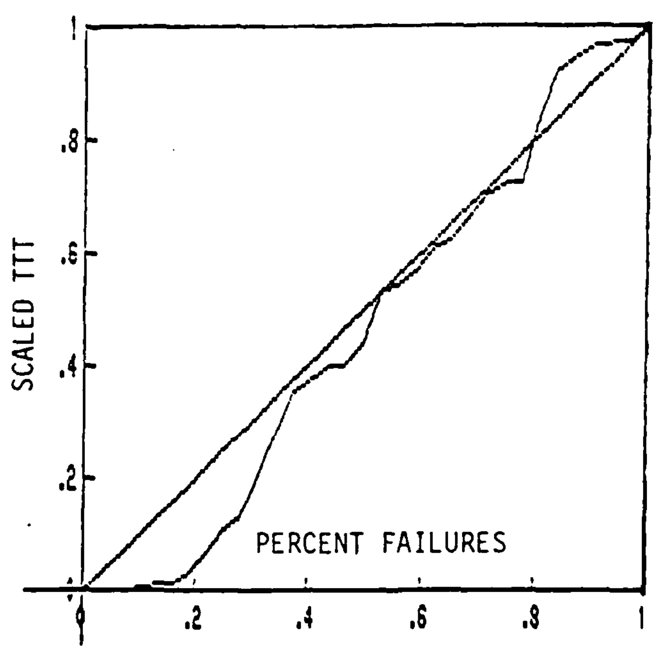


Figure 28. BTJ 3rd Lifetime (Original Data)

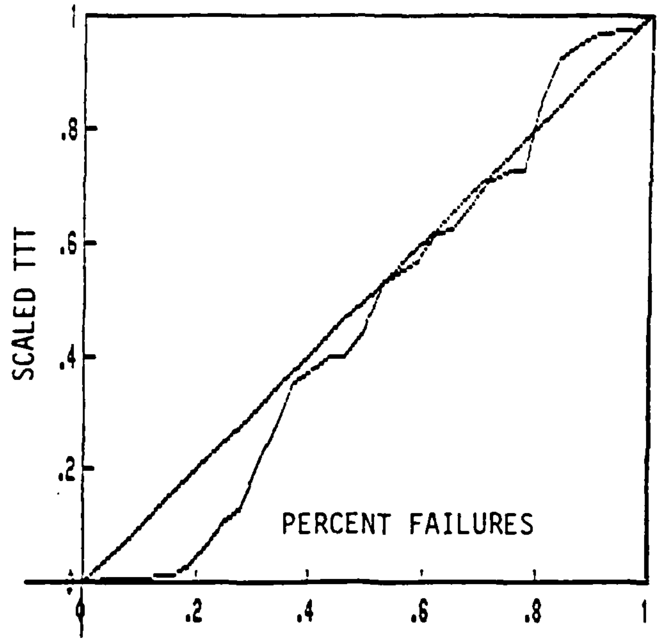


Figure 29. BTJ 3rd Lifetime
(Zero Values Assigned to 33)

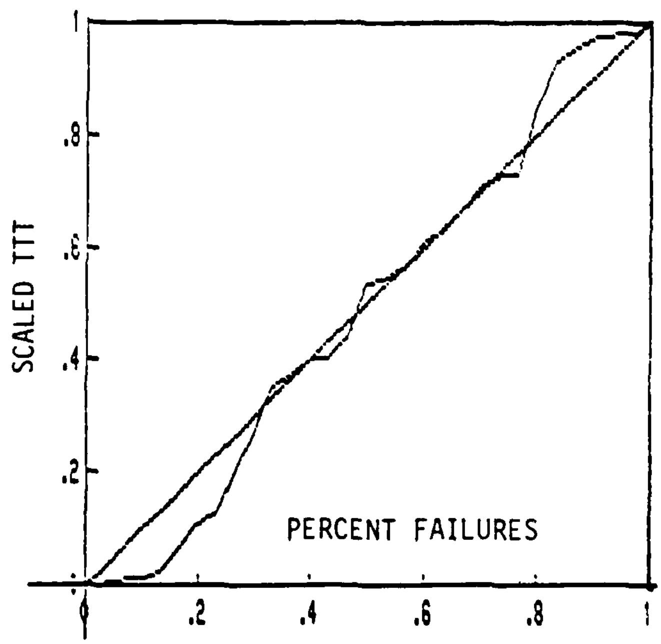


Figure 30. BTJ 3rd Lifetime
(Zero Values Deleted)

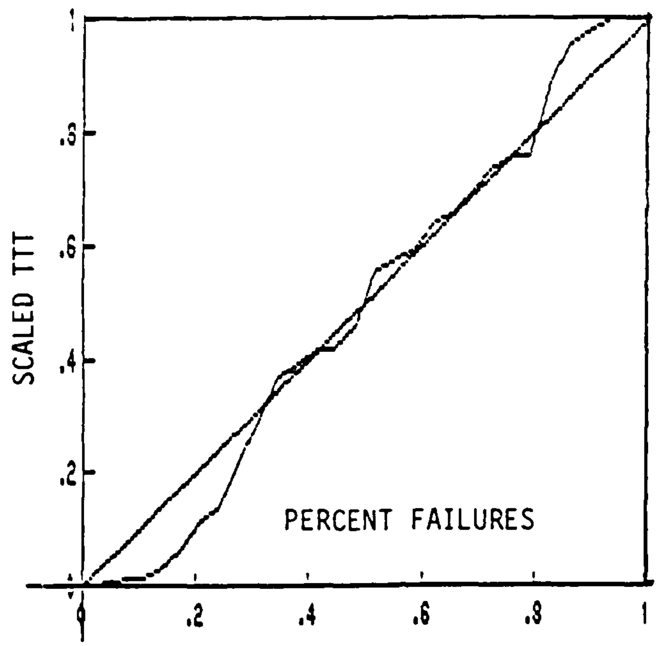


Figure 31. BTJ 3rd Lifetime
(High Value Deleted)

Summary

The use of the methodology contained in Chapter III of this research effort has provided the information necessary to answer the questions that prompted this effort:

1. Does the elimination of possible catastrophic failures affect the results obtained when using the total time on test transform method?

2. Determine the effects truncation has on the total time on test transform method.

3. Determine the robustness of total time on test plots.

On all three boards analyzed, and in each lifetime of the boards, the assignment of the zero time on test values to the time containing the lowest non-zero time on test showed little effect on the resulting TTT plot. When the zero values were eliminated from the sample, the resulting plot in each case showed a shift up toward the IFR region of the graph. If under the

assumption that the zero values are catastrophic failures, this research has shown that their elimination has a noticeable effect on the plot of the total time on test method. Additionally, by eliminating the zero values and also unusually high values in some cases, this truncation has shown a movement in the position of the TTT plot. Finally, the robustness of the total time on test plot is questionable in that the elimination of a small number of zero or low values causes a shift upward of the TTT plot which could increase or decrease the number of crossings on the 45 degree line, and therefore increase or decrease the assumption of exponentiality.

The final Chapter of this research includes the conclusions, recommendations, and recommendations for future research that this researcher feels have evolved from this effort.

V. Conclusions and Recommendations

Conclusions

This research has shown that the total time on test transform method and its corresponding data plot is influenced by the structure of the data that is being analyzed. Additionally, the results of this research show that the structure of the data being analyzed must be carefully considered before using the TTT plot to make a management decision on the type of failure characteristic displayed by an item. The possibility of the TTT plot shifting towards the IFR region with the deletion of zero values, as in this research, has implications when analyzing sample data. The deletion of zero time to failure values from a sample could effect the analysis of the resulting TTT plot in the following ways.

1. Increase or decrease the crossings on the 45 degree line, resulting in an increase or decrease of the assumption of exponentiality or useful life.

2. Possibly move the data plot from the DFR to the IFR region of the TTT plot, which would indicate that an item is displaying wearout instead of infant mortality.

In either of the above situations, management would be concerned with what action to take towards the displayed failure data because of the importance of knowing whether the data being analyzed is displaying the failure characteristics of useful life, increasing failure rate (wearout) or decreasing failure rate (infant mortality).

Recommendations

The structure of the failure data should be a consideration before using the total time on test method to determine if an item is failing in an increasing, decreasing, or constant rate. The elimination of possible outliers and low values, that are not representative of the populations being analyzed, is of critical importance before a decision by management can be made to increase or decrease environmental stress screening or establishing parts replacement policy. This research in no way implies that low time to failure values or unusually high time to failure values have no importance to management when analyzing failure data. Zero time to failure, for example, could be an indication of an item that was installed incorrectly or broken in transit. Additionally, this research does not imply the zero time to failure values are not representative of a population, only that the deletion of these values effects the results obtained when using the TTT method and its resulting plot.

Future Research

Future research in the area of the total time on test transform method and its corresponding plot should be concerned with the validity and accuracy of the TTT method when the results are used to provide management with information concerning the failure characteristics of an item. The prediction capability of the total time on test method is critical to its acceptance and use by management.

This research has not been mathematically rigorous and only pertains to the effects data structure have on the total time on test plotting method. Based on the findings of this research, the following areas are recommended for future study.

1. Use known data distributions and calculate the TTT plot and compare the results.

2. Determine if an item that contains actual failure data, and is known to be displaying wearout, has the same indications when analyzed using the TTT method.

3. Use a known population distribution, take a sample of that distribution, and see if the known population is explained accurately using the TTT method of analysis.

4. Investigate the deletion of values off the high end of a data set to see if the effect is similar to the findings in this research.

Appendix: Total Time on Test Program

```
10 'TOTAL TIME ON TEST PLOTTING TECHNIQUE
20 'WRITTEN BY CAPT WILLIAM RIMPO, MAJ JOHN KUTZKE, AND LTCOL CARLOS TALBOTT
30 '
40 CLS:PRINT"TOTAL TIME ON TEST ANALYSIS OF FAILURE DATA"
50 PRINT
60 PRINT "THIS PROGRAM CALCULATES A TOTAL TIME ON TEST STATISTIC FOR FAILURE
70 PRINT "DATA FROM A COMPLETE LIFE TEST, AS WELL AS FROM FIELD FAILURE DATA
80 PRINT "CONTAINING CENSORED UNITS.
90 PRINT
100 DIM A(500),TTT(500),STTT(500),B(500,21),C(500),LAST(500)
110 DEFINT G-J
120 '
130 PRINT "WELCOME TO TOTAL TIME ON TEST.
140 PRINT "IF YOU WOULD LIKE TO USE AN EXISTING DATABASE ON FILE, PRESS F.
150 PRINT "IF YOU WOULD LIKE TO CREATE A NEW DATA FILE, PRESS C.
160 PRINT "IF YOU WOULD LIKE TO ENTER DATA MANUALLY, PRESS M.
170 CLOSE #7
180 LET K=0
190 B$=INPUT$(1)
200   IF B$="F" THEN 230
210   IF B$="C" THEN 380
220   IF B$="M" THEN 530
230 I=1
240 '
250 'ARRAY C(I) STORES FAILURE INDICATOR: 1 FOR FAILURE, 0 FOR CENSORED DATA
260 'ARRAY A(I) STORES LIFETIMES
270 '
280 '
290 LINE INPUT "MY DATA FILE IS:  ";E$
300 I=1
310 OPEN "I",#1, E$
320 IF EOF (1) THEN 660
330 INPUT #1,C(I),A(I):PRINT C(I),A(I)
340 IF C(I)=1 THEN K=K+1
350 LET I=I+1
360 GOTO 320
370 PRINT
380 CLS:PRINT "YOU ARE ABOUT TO CREATE A DATAFILE WHICH YOU WILL NAME.
390 PRINT "PLEASE REMEMBER YOU FILE NAME.  AFTER THE LAST INPUT TYPE -1
400 PRINT "TO END DATA ENTRY.
410 '
420 LINE INPUT"MY DATA FILE NAME WILL BE:";  E$
430 '
440 OPEN "O",#7,E$
450 INPUT "ENTER 1 FOR FAILED UNIT, 0 FOR UNFAILED/WITHDRAWN UNIT";C(I)
460 INPUT "ENTER FAILURE/CENSORED TIME.";A(I)
470 IF C(I)=-1 THEN 500
480 WRITE#7,C(I),A(I)
490 PRINT: GOTO 450
500 CLOSE #7
510 GOTO 300
520 '
530 CLS:INPUT"ENTER NUMBER OF LIFETIMES";N
540 PRINT N
550 FOR I=1 TO N
560 INPUT "ENTER 1 FOR FAILED UNIT, 0 FOR UNFAILED/WITHDRAWN UNIT";C(I)
570 PRINT C(I)
580 INPUT"ENTER LIFETIME";A(I)
590 PRINT A(I)
600 '
610 'K COUNTS THE NUMBER OF FAILURES
620 '
630 IF C(I)=1 THEN K=K+1
640 PRINT K
650 NEXT I
660 N=I-1
670 REALN!=N
680 '
690 'OPENS FILES TO STORE TTT STATISTICS
700 '
```

```
710 OPEN "O",8,"AGE1.DAT"
720 '
730 'HERE THE ARRAY A(I) RECORDS UNORDERED LIFETIMES
740 'NOW SORT A(I) TO ORDERED LIFETIMES
750 '
760 LET F=0
770 FOR I=1 TO N-1
780 IF A(I)<=A(I+1) THEN GOTO 830
790 LET TEMP=A(I)
795 LET TEMPC=C(I)
800 LET A(I)=A(I+1)
805 LET C(I)=C(I+1)
810 LET A(I+1)=TEMP
815 LET C(I+1)=TEMPC
820 LET F=1
830 NEXT I
840 '
850 'IF F=1 THEN ORDER ISN'T PERFECT YET
860 '
870 IF F=1 GOTO 760
880 LINE INPUT "MY ORDERED DATA FILE IS:"; F$
890 OPEN "O",#5, F$
900 PRINT,"THE SET OF ORDERED LIFETIMES IS:"
910 FOR I=1 TO N
920 PRINT, I, "      "C(I),A(I)
930 WRITE #5,C(I),A(I)
940 NEXT I
950 CLOSE #5
960 '
970 'TOTAL TIME ON TEST SUBROUTINE
980 '
990 LET G=0
1000 FOR J=1 TO N
1010 IF C(J)=1 THEN G=G+1
1020 IF J=1 THEN TTT(J)=N*A(J)
1030 IF J=1 GOTO  1050
1040 LET TTT(J)=TTT(J-1)+(N-J+1)*(A(J)-A(J-1))
1050 IF C(J)=1 THEN TEMP=TTT(J)
1060 LET LAST(G)=TEMP
1070 NEXT J
1080 '
1090 'SCALED TTT SUBROUTINE
1100 'CALCULATES A SCALED TTT FOR FAILURES ONLY.
1110 '
1120 FOR I=1 TO G
1130 '
1140 STTT(I)=LAST(I)/LAST(G)
1150 IF I=G THEN PRINT#8,0;0
1160 IF I=G THEN PRINT#8,1;1
1170 IF I=G THEN PRINT#8,0;0
1180 NEXT I
1190 PRINT
1200 PRINT "                SCALED TTT     VS      PERCENT FAILURES
1210 FOR F=1 TO K
1220 PRINT#8,STTT(F);F/K
1230 PRINT, STTT(F),"",F/K
1240 NEXT F
1250 '
1260 END
```

Bibliography

1. Armstadter, Bertram C. Reliability Mathematics: Fundamentals, Practices, Procedures. New York: McGraw Hill, Inc., 1971.

2. Barlow, Richard E. and Raphael Campo. "Total Time on Test Processes and Application tc Failure Data Analysis," Reliability and Fault Tree Analysis, edited by R. E. Barlow, J. Fussel, and N. D. Singpurwalla. Philadelphia: SIAM, 451-481, 1975.

3. Barlow, Richard E. and Bernard Davis. "Total Time on Test Plots," Proceedings of the Twenty-Fourth Conference on the Design of Experiments in Army Research Development and Testing, ARO Report 79-2, 361-380 (1979).

4. Barlow, Richard E. and Frank Proschan. Mathematical Theory of Reliability, New York: John Wiley and Sons, Inc., 1965.

5. Barnett, Vic and Toby Lewis. Outliers in Statistical Data. New York: John Wiley and Sons, Inc., 1984.

6. Bazovsky, Igor. Reliability Theory and Practice. Englewood Cliffs NJ: Prentice-Hall, Inc., 1962.

7. Bergman, Bo. "Crossings in the TTT Plot." Scan. Journal of Statistics, 4: 171-177 (1977).

8. ----. "Some Graphical Methods for Maintenance Planning," 1977 Proceedings Annual Reliability and Maintainability Symposium. 467-471, (1977).

9. Green, A. E. and A. J. Bourne. "An Approach to Reliability Assessment," Reliability and Fault Tree Analysis, edited by R. E. Barlow, J. Russel and N. D. Singpurwalla. Philadelphia: SIAM, 895-912, 1975.

10. Huber, Peter J. Robust Statistics. New York: John Wiley and Sons, Inc., 1981.

11. Juran, J. M. and Frank M. Gryna, Jr. Quality Planning and Analysis. New York: McGraw Hill Book Company, 1980.

12. Kalbfleisch, John D. and Ross L. Prentice. The Statistical Analysis of Failure Time Data. New York: John Wiley and Sons, Inc., 1980.

13. Lawless, J. F. Statistical Models and Methods for Lifetime Data. New York: John Wiley and Sons, Inc., 1982.

14. Nelson, Wayne. Applied Life Data Analysis. New York: John Wiley and Sons, Inc., 1982.

15. Russ, Lt Gen Robert D. "Fourth Wheel on the Acquisition Wagon," Air Force Magazine, 12: 122-124 (March 1985).

16. Sisk, Albert E. A Description of the Failure Distributions of Selected Minuteman III Guidance System Cards. MS Thesis, AFIT/GLM/LSM/86S-76, School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1986.

17. Talbott, Lt Col Carlos M., Jr. Graphical Techniques for Maintenance Planning. PhD Dissertation. School of Engineering and Applied Science, George Washington University, Washington DC, February, 1986.

18. Trapp, R. D. and others. An Approach for Assessing Missile System Dormant Reliability, Final Report. The BDM Corporation, Albuquerque NM, 1981.

Vita

Captain Thomas J. Edwards was born on 21 August 1952 in Coaldale, Pennsylvania. He graduated from high school in Tamaqua, Pennsylvania in 1970. He enlisted in the Air Force in November 1971 and was released from active duty in June 1977. He attended San Jose State University at San Jose, California and received a Bachelor of Science in Industrial Technology in January 1981. Upon graduation, he was commissioned in the Air Force through the ROTC program. He was called to active duty in March 1981 and completed Operational Readiness Training for the Minuteman III ICBM Weapon System in July 1981. He then served as a Missile Launch Officer at F.E. Warren AFB, Wyoming until April 1986 when he entered the School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH, in May 1986.

Permanent Address: 131 Gay Street
Tamaqua, Pennsylvania
18252

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GLM/LSMB/87S-21	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL *(If applicable)* AFIT/LSM	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State, and ZIP Code)* Air Force Institute of Technology Wright-Patterson AFB OH 45433-6583	7b. ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO

11. TITLE *(Include Security Classification)*
THE EFFECTS OF DATA STRUCTURE ON TOTAL TIME ON TEST PLOTS

12. PERSONAL AUTHOR(S)
Thomas J. Edwards, B.S., Capt USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1987 September	59

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
12	03	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Reliability, Probability Distribution Identification, Total Time on Test, Data Plots

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Thesis Chairmanship: Phillip E. Miller, Major USAF
Assistant Professor of Logistics Management

Approved for public release: ...
Lynn E. Wol...
Lynn E. WOL...
24 Sep 87
Dean for R...
Air Force In...
Wright-Patterson AFB ...

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Phillip E. Miller, Major USAF	22b. TELEPHONE *(Include Area Code)* 513 255-5023 22c. OFFICE SYMBOL AFIT/LSM

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Block 19. Abstract

This research describes the effects data structure has on the Total Time on Test Transform technique and the resulting interpretation of the plot. Specifically, actual failure data on three card types (SUQ, BQQ, and BTJ) located in the Minuteman III Missile Guidance System was analyzed after manipulation. The manipulation consisted of the following three steps: 1) assign all zero time to failure values to the lowest failure time other than zero, 2) delete the zero time to failure values, and 3) delete all unusually high values from the sample data. AFter each step, the data was calculated and analyzed using Zenith 100 computer programs which performed the total time on test calculations and graphed those calculations into a total time on test data plot.

The results of this analysis indicated that data structure does influence total time on test plots. The deletion of the zero time to failure values causes a movement upward of the data plot which could 1) decrease the indication of decreasing failure rate (DFR), 2) increase or decrease the number of crossings on the 45 degree line, and 3) increase the indication of increasing failure rate (IFR).

END
DATE
FILMED
FEB.
1988